

OPTICAL FIBER FOR ATTENUATING OPTICAL SIGNAL

This application claims priority to Japanese Patent Application No. 2002-34322, filed on November 27, 2002, the complete disclosure of which is
5 incorporated herein by reference.

Background of the invention

1. Field of the invention

10 The present Invention relates to an optical fiber for attenuating optical signal, which is used in optical attenuator, optical terminal device or the like.

2. Description of the Related Art

In recent years, optical fiber communication network has made rapid progress. In
15 the optical fiber communication network, a variety of optical devices are used.

As one of the optical devices, there is an optical fixed attenuator, it is used to positively attenuate optical signal for adjusting the light power level in the optical fiber communication network into proper scope.

Further, As another of the optical devices, there is a optical terminal device, it is
20 used to reflect the input light in its own output side and make the reflected light return, then attenuate the light having returned, for removing the influence of unnecessary optical signal.

In these optical devices, generally, optical fiber for attenuating optical signal is used. The optical fiber for attenuating optical signal has a core formed from quartz glass, which has a higher refractive index by doping Ge (germanium). In the core, Co (cobalt) is contained
25 as a dopant (doped material) to positively attenuate optical signal.

Moreover, in WDM (Wavelength Division Multiplexer) network, the optical fixed

attenuator or the optical terminal device is needed extremely. In the WDM network system, there are many kinds of wavelengths with respect to various transmitted lights, the attenuation amount of the optical fixed attenuator or the optical terminal device must correspond to anyone of wavelengths.

5 Therefore, the optical fiber for attenuating optical signal, used in the optical fixed attenuator or the optical terminal device, it is requested to realize same attenuation amount, not only corresponding to the optical signal with the wavelength of 1310 nm or 1550 nm, but also corresponding to the optical signal with wider scope's wavelength.

10 Conventionally, in order to obtain such fiber for attenuating optical signal, whose light attenuation amount is constant, there is a method (for example, patent document 1) to be provided. The method uses a characteristic that mode field diameter (MFD) depends upon the wavelength of the transmitted optical signal, and adds dopant to the narrow area in core, then sets most appropriately construction.

The patent document 1: Japanese Patent publication 8-136736.

15 However, in the conventional art, there are some problems to need to be solved.

 That is, Co is a dopant used in the optical fiber for attenuating optical signal as usual. As a characteristic of the Co, the more the wavelength of optical signal is long, the more the Co absorbs the optical signal. Because the dopant absorbs the optical signal, the optical signal is attenuated. By using the Co having such characteristic and add it to core, the optical
20 fiber for attenuating optical signal is formed, which can obtain stable attenuation amount with respect to various optical signals with various wavelengths. Thus, as stated above, it is possible to use a characteristic depending upon the wavelength of optical signal transmitted by mode field diameter (MFD), to add dopant to the narrow area in core, and to set most appropriately construction.

25 However, when using such method, which adds dopant to the narrow area in core, the passage of the optical signal becomes narrow. Therefore, in order to obtain the requested

attenuation amount, it is necessary to improve the concentration of the Co. in the case, when using a method called sinking method; it is difficult to add Co with higher concentration.

Summary of the invention

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To solve the conventional problems as mentioned above, the present invention provides an optical fiber for attenuating optical signal, which can have the same attenuation amount with respect to various optical signals corresponding to wide wavelength scope.

According to the present invention, there is provided an optical fiber for attenuating
10 optical signal, including a core and a cladding wherein n ($n \geq 2$) kinds of dopants are added for attenuating optical signal,

wherein the concentration W_j ($j=1, 2, 3, \dots, n$) is adjusted, with respect to wavelength λ_i ($i=1, 2, \dots, m; m \geq 2$), as meeting the following expressions 1 and 2.

Expression 1:

$$0.9 < \frac{\alpha(\lambda_i)}{\alpha(\lambda_k)} < 1.1 \quad (k=1, 2, \dots, m) \quad \text{AND} \quad (k \neq i)$$

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Expression 2:

$$\alpha(\lambda_i) = \sum_{j=1}^n W_j A_j(\lambda_i)$$

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.i, is a wavelength of optical signal used in optical communication system;

.(i), is an attenuation amount of fiber for attenuating optical signal with respect to optical signal with wavelength.i, its unit is dB;

K is a positive integral number;

5 W_j is a concentration of dopant j;

$A_j(i)$ is an attenuation of fiber for attenuating optical signal with respect to the optical signal with wavelength.i, which is produced by the dopant j of one unit.

In the optical fiber for attenuating optical signal, the dopant preferably comprises at least two kinds of transitional metals selected from Co, Ni, Cr, V, Fe, Mn, Tb and Tm.

10 Further, in the optical fiber for attenuating optical signal, the doped area (cladding) the dopant is doped is preferably about six times area of the core around the core as a center. The diameter of doped area is preferably about six times the diameter of core.

Moreover, in the optical fiber for attenuating optical signal, the wavelength .i of optical signal is preferably in the range of 1200-1700 nm. In this case, the wavelengths .i of
15 optical signal, for example, may be 1310 nm and 1550 nm.

Furthermore, the optical fiber for attenuating optical signal, with respect to the wavelengths .i of optical signal, preferably operates in single mode.

Further, in the optical fiber for attenuating optical signal, the distribution of the dopant in the doped area is preferably not uniform along the radius direction of the optical
20 fiber.

Moreover, in the optical fiber for attenuating optical signal, the dopant enabling the absorption of optical signal to increase with the wavelength become long, and the dopant enabling the absorption of optical signal to decrease with the wavelength become long, are preferably simultaneously added.

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Brief description of the Drawings

The above and other objects, advantages and features of the present invention will
5 be more apparent from the following description taken in conjunction with the
accompanying drawings in which:

Figs. 1a and 1b show a longitudinal section and a cross section showing a state that
fiber for attenuating optical signal of the present invention is inserted into a ferrule;

Fig. 2 is a graph showing the wavelength characteristic of dopant for attenuating
10 optical signal;

Fig. 3 is an attenuation amount list showing the wavelength characteristic of dopant
for attenuating optical signal;

Fig. 4 is a graph showing wavelength characteristic of optical fiber doped only by
Co, between wavelength and attenuation amount;

15 Fig. 5 is a graph showing wavelength characteristic of optical fiber doped only by V,
between wavelength and attenuation amount; and

Fig. 6 is a graph showing wavelength characteristic of fiber for attenuating optical
signal, between wavelength and attenuation amount.

20 Description of the preferred Embodiments

Best modes of carrying out the present invention will be described in further detail
using various embodiments with references to the accompanying drawing without being
limited thereto.

25 Next, details explain the embodiments regarding implementation aspects.

Figs. 1a and 1b show an example of optical attenuator or optical terminal device, in

which, the optical fiber for attenuating optical signal is placed in ferrule.

Fig. 1a is a longitudinal section showing a part of optical attenuator or optical terminal device, Fig. 1b is a cross section showing a part of optical attenuator or optical terminal device.

5 In Figs. 1a and 1b, 1 is a fiber for attenuating optical signal of the present invention, whose core is doped by dopant for attenuating optical signal. Serving as the optical fiber for attenuating optical signal 1, in general, single mode fiber is used. The outside diameter of the optical fiber for attenuating optical signal 1 is 125 μm . The optical fiber for attenuating optical signal 1 is inserted into a ferrule 2 with an inside diameter of 126 μm , and is fixed
10 with the ferrule 2 by adhesive. The optical fiber for attenuating optical signal 1 has a standard length of 22.4 mm. The ferrule 2, in which the optical fiber for attenuating optical signal 1 is inserted, is placed in un-shown optical connector, and then forms a part of optical attenuator or optical terminal device.

 In present invention, preferably at least two kinds of dopant for attenuating optical
15 signal are added simultaneously into optical fiber (the meaning regarding the “added simultaneously” is: a plurality of dopants are added i.e. doped), then it is possible to obtain approximate same attenuation amount with respect to optical signals with different wavelengths in wide wavelength scope. Thus, the attenuation amounts of light amounts become flat. That is, if only adding simultaneously respective dopants for attenuating optical
20 signal to optical fiber such as meeting the conditions shown by the following expressions, the above-stated object can be reached.

[Expression 1]

$$0.9 < \frac{\alpha(\lambda_i)}{\alpha(\lambda_k)} < 1.1$$

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(K=1, 2, ..., m) and (k ≠ i)

The expression 1 means that: with respect to any one of m kinds of optical signals that are actually transmitted in optical fiber and have respective wavelengths, the unevenness of attenuation amount is in the range of 0.9 ~ 1.1 dB. λ_i is a wavelength of optical signal used in optical communication system; $\alpha(\lambda_i)$ is an attenuation amount of fiber for attenuating optical signal with respect to optical signal with wavelength λ_i , its unit is dB. the denominator $\alpha(\lambda_k)$ is a object for comparing, indicates a attenuation amount with respect to optical signals with all other wavelengths.

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[Expression 2]

$$\alpha(\lambda_i) = \sum_{j=1}^n w_j A_j(\lambda_i)$$

The expression 2 indicates that: with respect to one optical signal with any of wavelengths, its attenuation amount is the sum total produced by all dopants added in optical fiber. W_j is a concentration of dopant j ; its unit is weight %. $A_j(\lambda_i)$ is an attenuation of fiber for attenuating optical signal with respect to the optical signal with wavelength λ_i , which is produced by the dopant j of one unit. Therefore, $W_j A_j(\lambda_i)$ indicates a total attenuation amount of the optical fiber for attenuating optical signal with respect to the optical signal with wavelength λ_i , which is produced by the dopant j . Because there are n dopants being added, at the right side of the expression 2, the attenuation amount, produced by the n kinds of dopants, of the optical fiber for attenuating light with respect to the optical signal with wavelength λ_i , is attained.

Fig. 2 is a graph showing the wavelength characteristic of respective dopants for attenuating optical signal.

The dopants \sim for attenuating optical signal, as known from past, respectively have peculiar characteristics that the attenuation amounts of these optical signals are different corresponding to respective wavelengths. This data is obtained by respectively, uniformly adding dopants for attenuating optical signals into the whole core of the optical fiber along the length direction and the radius direction, and by manufacturing the optical fiber for attenuating optical signal on the same manufacturing conditions, then by measuring their absorption wavelength characteristic.

The refractive index ratio of core to cladding of the optical fiber is 0.3%. In the core of the optical fiber, Ge is doped as a dopant for improving refractive index. The cladding of the optical fiber is formed by pure quartz glass. The outside diameter of the core is 8 μm . The concentration of the dopant is set in 1000 ~ 10000 ppm. The concentration is such concentration enabling the optical signal attenuation amount is in 1 ~ 10 dB/cm.

Fig. 3 is an attenuation amount list showing the wavelength characteristic of dopant for attenuating optical signal. In Fig. 3, the optical signal attenuation amount is also shown

when the dopant of 1 ppm for attenuating optical signal is added into the optical fiber having a length of 1 m, with respect to the optical signals with wavelengths 1310 nm and 1550 nm, mainly used in optical communication.

Further, on the one hand, it is known that transitional metal contained in glass exists in ion state. For example, V may be V^{3+} , V^{4+} , or V^{5+} ; Cr may be Cr^{3+} , or Cr^{6+} ; Mn may be Mn^{2+} , or Mn^{3+} ; Fe may be Fe^{2+} , or Fe^{3+} ; Co may be Co^{2+} , and Ni may be Ni^{2+} . In these, V, Cr, Mn and Fe exist in at least two kinds of ion states with different the number of valent. The ratio (in balance state) of the at least two kinds of ion states is influenced greatly by the atmosphere of manufacturing glass. The atmosphere is oxidation atmosphere, reduction atmosphere or the like. In general, if the glass is manufactured in the oxidation atmosphere, the ratio of the ion state with small the number of valent will be increased; and if the glass is manufactured in the reduction atmosphere, the ratio of the ion state with big the number of valent will be increased. When the number of valent of the transitional metal ion contained in glass changes, because the absorption wavelength characteristic of optical signal also changes, then the absorption wavelength characteristic of glass including the transitional metal ion is changed by the manufacturing atmosphere of the glass.

On the other hand, it is known that the arrangement states of the Co^{2+} , Ni^{2+} and Fe^{3+} depend upon the cooling speed of the glass. Because of the difference of arrangement states, with respect to the glass in which the transitional metal ion is added, its absorption wavelength characteristic of optical signal changes. When the reduction speed of the optical fiber, because the cooling speed become different, the absorption wavelength characteristic of optical signal changes. In view of the above various conditions, by selecting it in which most proper transitional metals are combined, it is better to manufacture the optical fiber for attenuating optical signal. Moreover, in the optical fiber used in communication, because the optical signal is transmitted in single mode, so the optical fiber for attenuating optical signal is desired to operating in single mode, with respect to the optical signal with wavelength .i.

Further, the attenuation amount of the optical fiber for attenuating optical signal is influenced by the concentration distribution of the dopant for attenuating optical signal in optical fiber, and by the mode distribution of the optical signal transmitted in the optical fiber. If making the attenuation amount serve as a standard value, obtained in the case that the dopant distributes over the whole of the core and the cladding of the optical fiber, in uniform concentration, when the dopant is distributed only over the center portion of the core, the attenuation amount of optical signal become small if being comparing with the standard value. Further, when the scope the dopant distributed becomes broad, the attenuation amount of optical signal become big by comparing with the standard value. When the dopant distributes over the area, which equals the 6 times of the center portion, from the center of the core, the attenuation amount of optical signal become approximately the standard value. Therefore, it is desired to uniformly distribute the dopant over the area equaling the 6 times of the center portion, from the center of the core.

Moreover, the mode distribution of the optical fiber (in particular, with respect to single mode fiber) is influenced by optical diffractive effect. Therefore, when the wavelength becomes long, the mode distribution become broad. That is, the optical signals with various modes are transmitted in optical fiber. In the case that the dopant distributes only over the center portion of the core, with the mode distribution spreads out, the attenuation amount of all optical signals become small. In other words, depending upon the spreading manner of the mode distribution, the wavelength dependence characteristic makes a change. The spreading manner of the mode distribution is greatly influenced by the refractive index distribution of the core and the cladding of the optical fiber. As a result, the refractive index distribution of the core and the cladding makes the wavelength dependence characteristic receive great influence.

In the above argument, there is a precondition that the dopant having the attenuation characteristic for optical signal is contained uniformly in the optical fiber. However, even if

the concentration distribution of the dopant is not uniform by seeing along the radius direction of the optical fiber, with respect to the attenuation amount of optical signal, the wavelength characteristic occurs. That is, the concentration distribution of dopant is an important parameter on the design of the optical fiber for attenuating optical signal.

5 In the present invention, as stated above, though the wavelength characteristic of attenuation amount changes by depending upon the concentration distribution of dopant, the refractive index distribution of core and cladding, and the like, either the concentration distribution of dopant, or the refractive index distribution of core and cladding, if only adding the dopant as meeting the conditions indicated by the above expressions 1 and 2, the
10 object of the present invention can be reached. Therefore, there is such an effect that it is possible to use the optical fiber wherein the concentration distribution of the dopant is not uniform by seeing along the radius direction of the optical fiber.

[Embodiments]

Next, to concretely indicate the embodiments when several dopants for attenuating
15 light are simultaneously added to the optical fiber. In these embodiments, any fiber for attenuating optical signal is a single mode, and Ge is added in the optical fiber for improving the refractive index of core.

Embodiment 1:

In the embodiment, the optical fiber for attenuating optical signal is manufactured
20 by using V and Co serving as the dopant for attenuating optical signal.

Fig. 4 is a graph showing wavelength characteristic of optical fiber doped only by Co, between wavelength and attenuation amount; Fig. 5 is a graph showing wavelength characteristic of optical fiber doped only by V, between wavelength and attenuation amount. In these drawings, the vertical axis indicates the attenuation amount by any scale.

25 Further, Fig. 6 is a graph showing wavelength characteristic of fiber for attenuating optical signal, between wavelength and attenuation amount, when V and Co are

simultaneously added as dopants. In the Fig. 6, the vertical axis indicates the attenuation amount with respect to the optical fixed attenuator or the optical terminal device with a standard length of 22.4 mm. The weight ratio (V : Co) of V to Co is 1 : 3 when the V and the Co are simultaneously added. With respect to the optical signals with wavelengths 1310 nm and 1550 nm, the attenuation amount ratio (attenuation amount of 1310 nm optical signal / attenuation amount of 1550 nm optical signal) is 0.95.

With respect to the attenuation amount of optical fiber in Fig. 4 and 5, wavelength characteristic is not small. On the one hand, Co is such dopant as that: the more the wavelength is long, the more the absorption of optical signal increases. On the other hand, V is such dopant as that: the more the wavelength is long, the more the absorption of optical signal decreases.

Thus, in the optical fiber corresponding to the Fig. 6, the attenuation amount ratio is 0.9 – 1.1. In the optical fiber for attenuating optical signal of the embodiment, it is proved that the wavelength characteristic of attenuation amount is approximately flat. Therefore, when simultaneously adding the dopant making the absorption of optical signal increase with the wavelength become long and the dopant making the absorption of optical signal decrease with the wavelength become long, it is possible to make the wavelength characteristic of attenuation amount effectively become flat.

Embodiment 2:

In the embodiment, the optical fiber for attenuating optical signal is manufactured by using Fe and Ni serving as the dopant for attenuating optical signal. The weight ratio (Fe : Ni) of Fe to Ni is 1 : 0.3 when the V and the Co are simultaneously added. With respect to the optical signals with wavelengths 1310 nm and 1550 nm, the attenuation amount ratio (attenuation amount of 1310 nm optical signal / attenuation amount of 1550 nm optical signal) is 1.03. In the embodiment, with respect to the optical fiber for attenuating optical signal, it is also proved that the wavelength characteristic of attenuation amount is

approximately flat.

Embodiment 3:

In the embodiment, the optical fiber for attenuating optical signal is manufactured by using Fe and Co serving as the dopant for attenuating optical signal. The weight ratio of Fe to Co is 1 : 0.23 when the V and the Co are simultaneously added. With respect to the optical signals with wavelengths 1310 nm and 1550 nm, the attenuation amount ratio is 1.01. In the embodiment, the wavelength characteristic of attenuation amount is also approximately flat.

Embodiment 4:

In the embodiment, the optical fiber for attenuating optical signal is manufactured by using V and Cr serving as the dopant for attenuating optical signal. The weight ratio of V to Cr is 1 : 40 when the V and the Co are simultaneously added. With respect to the optical signals with wavelengths 1310 nm and 1550 nm, the attenuation amount ratio is 1.00. In the embodiment, the wavelength characteristic of attenuation amount is also approximately flat.

Embodiment 5:

In the embodiment, the optical fiber for attenuating optical signal is manufactured by using Mn and Co serving as the dopant for attenuating optical signal. The weight ratio of Mn to Co is 1 : 0.04 when the V and the Co are simultaneously added. With respect to the optical signals with wavelengths 1310 nm and 1550 nm, the attenuation amount ratio is 1.06. In the embodiment, the wavelength characteristic of attenuation amount is also approximately flat.

Embodiment 6:

In the embodiment, the optical fiber for attenuating optical signal is manufactured by using three kinds of elements of Mn, Ni and V serving as dopants for attenuating optical signal. The weight ratio of Mn to Ni to V is 1 : 0.6 : 0.15 when they are simultaneously added. With respect to the optical signals with wavelengths 1310 nm, 1450 nm and 1550 nm,

the attenuation amount ratio is 1 : 0.98 : 0.97. In the embodiment, the wavelength characteristic of attenuation amount is also approximately flat.

Embodiment 7:

In the embodiment, the optical fiber for attenuating optical signal is manufactured by using three kinds of elements of Co, Fe and Ni serving as dopants for attenuating optical signal. The weight ratio of Co to Fe to Ni is 1 : 33 : 2.7 when they are simultaneously added. With respect to the optical signals with wavelengths 1450 nm, 1550 nm and 1650 nm, the attenuation amount ratio is 1 : 0.95 : 0.95. In the embodiment, the wavelength characteristic of attenuation amount is also approximately flat.

Embodiment 8:

In the embodiment, the optical fiber for attenuating optical signal is manufactured by using Fe in core and using Ni in cladding, serving as dopants for attenuating optical signal. In order to use the light oozing to the cladding and make the attenuation amounts of at least two kinds of optical signals with different wavelengths become same, in the cladding, the dopant is also doped near the core. The weight ratio of Fe to Ni is 1 : 0.49 when they are simultaneously added. With respect to the optical signals with wavelengths 1310 nm and 1550 nm, the attenuation amount ratio is 1 : 0.99. In the embodiment, the wavelength characteristic of attenuation amount is also approximately flat.

Embodiment 9:

In the embodiment, the optical fiber for attenuating optical signal is manufactured by using Fe and V in cladding, serving as dopants for attenuating optical signal. That is, only the cladding serves as a doped area. The weight ratio of Fe to V is 1 : 0.36 when they are simultaneously added. With respect to the optical signals with wavelengths 1310 nm and 1550 nm, the attenuation amount ratio is 1.00. In the embodiment, the wavelength characteristic of attenuation amount is also approximately flat.

As an effect of the present invention, by using at least two kinds of dopants for

attenuating optical signal, to be simultaneously added in optical fiber, it is possible to supply the optical fiber for attenuating optical signal enable the attenuation amount to become flat in wide wavelength scope.